

Interferometric Observations of Geosynchronous Satellites

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Abstract—In recent years, a large number of geosynchronous satellites are being planned to provide augmentation services for enhancing the precision to global positioning systems, e.g., GPS, in applications such as aircraft landing. In this paper, we present a scheme for co-locating passive satellite observational facilities with a radio astronomy facility to open a new possibility of providing valuable data for radio astronomical imaging, ionospheric studies and satellite orbit estimation.

Index Terms—Interferometry, Navigation Satellites, Radio Astronomy

I. INTRODUCTION

IN recent years, an increasing number of geosynchronous satellites are being planned to cope with the need of providing regional navigation services or augmentation to global systems like the GPS. From various announcements made by the Indian Space Research Organization (ISRO), one can expect at least 9 geosynchronous satellites to be commissioned by ISRO within the next few years with dual frequency synchronized payloads [1][2]. Among these, the first satellite, GSAT-8, has been launched recently and is likely to commence regular broadcast of WAAS messages from September 2011, as part of the GAGAN project [1]. GAGAN aims to enhance the precision achievable by GPS-based systems for assisting air-craft landing. A second geosynchronous satellite with a GAGAN payload has been announced for launch during early 2012. Both these broadcast WAAS messages on the L1 (1575 MHz) and L5 (1176 MHz) carriers.

These satellites will soon be followed by a series of geosynchronous satellites with dual frequency (L and S-band) navigation payloads as part of the Indian Regional Navigation Satellite System (IRNSS)[1]. All these, and perhaps some satellites for digital audio broadcasting, have a unique advantage of continuous visibility from the Indian subcontinent. (e.g., nine or more L-band signals from geosynchronous satellites are visible all the time). This brings an interesting combination of benefits to radio astronomy and satellite orbit estimate requirements. Here, passive interferometry is used between signals received at different locations within the space covered by a synthesis radio telescope like the Giant Meterwave Radio Telescope (GMRT). We refer the reader to [3] for an example of a satellite observation with such a co-located facility.

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II. SATELLITE INTERFEROMETRY: BASIC GEOMETRY AND RECEIVERS

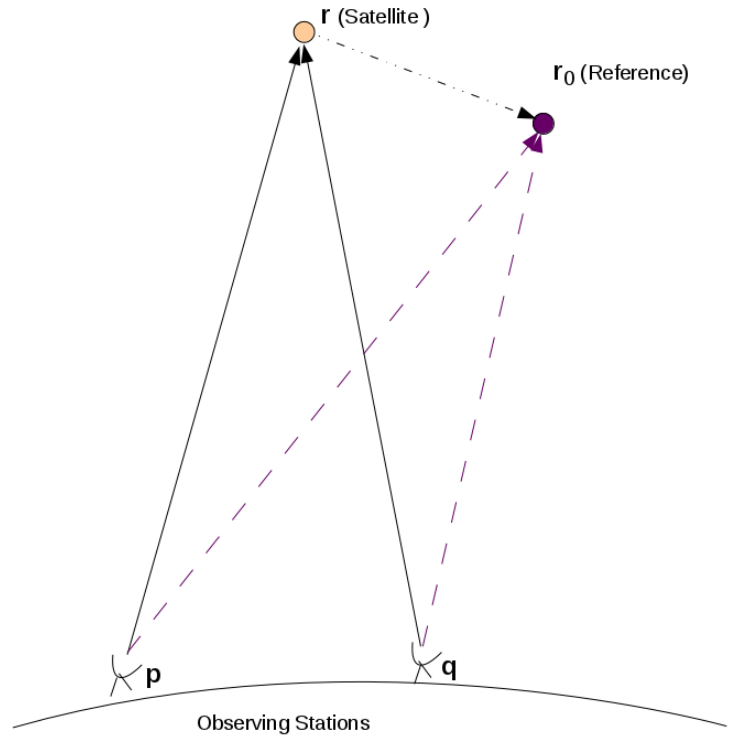


Figure 1. Schematic showing the configuration of the interferometer.

A simple illustration of the geometry of interferometry is given in Fig. 1. In this figure, offset of the state vector with respect to a reference position is represented by $\delta \mathbf{r} = (\mathbf{r} - \mathbf{r}_0)$, where, \mathbf{r}_0 is a reference position, and \mathbf{r} is the true position of the satellite. Similarly, satellite velocity is then given by $\delta \mathbf{v} = \frac{d(\delta \mathbf{r})}{dt}$. A cross-correlation of the signals received at two stations in two different frequencies can be used to measure instantaneous values of the components of $\delta \mathbf{r}$ and $\delta \mathbf{v}$ along the baseline vector joining the two receiving stations. Initial value for the reference position is generally available (or obtainable

as two-line elements from the Internet) and can be updated using the interferometric measurements using a suitable orbit propagation software.

In view of the wide variety of inexpensive antennas and receivers available off-the-shelf for receiving satellite signals, it is possible to construct a simple system for satellite interferometry (and co-locating with a Radio Astronomy facility) to obtain valuable data for radio astronomical imaging, ionospheric studies and satellite orbit estimation. A preliminary attempt for realizing such a co-located system with the GMRT was attempted by us in 2005. The subsystems developed for this project are being augmented to establish a simple facility at the Raman Research Institute. A conceptual description of the system constituting this facility has been given in Fig. 2.

This facility consists of a common L-band subsystem interfaced to off-the-shelf RF units corresponding to the satellite C, L or Ku-band. It may be noted that the primary navigation signals are in the L-band, and provide the most valuable information on the satellite range/Doppler or ionospheric delay along the line of sight. While this is the most useful band for measuring ionospheric contribution to interferometric phases for observing a celestial radio source, the satellite orbit estimation problem itself requires supplementary data using interferometric observations which are sensitive to satellite state vector components along directions perpendicular to the line of sight. In this connection, we note that the information related to components orthogonal to the line of sight is a natural outcome of radio interferometry.

Furthermore, since radio interferometry provides a measure of the arrival time differences of signals reaching different array elements, it does not require any knowledge of the nature of signals broadcast by the satellite. Hence, any band-limited signal transmitted by the satellite can be used for this purpose. A cross-correlation of the signals - (after compensating for delay differences resulting from an assumed reference), provides an estimate of the arrival time differences in excess of those that can be traced to the reference.

In view of the inherent signal strength coming from satellites, the required bandwidths and integration times are well within simple processing capabilities of a normal workstation. However, the angular resolution which can be achieved by this method (which improves with decreasing wavelength) depends on the array extent measured in units of wavelength. We propose to exploit this fact, and the decreasing importance of ionosphere at higher frequencies, to use the available high frequency signals from the satellite for interferometry. Interestingly, ALL the geosynchronous satellites operated by ISRO (including those with GAGAN or IRNSS payloads) will have their telemetry signals operating in the C-band. On the other hand, the recently launched satellite (GSAT-8) with a GAGAN payload has a rich set of communication transponders in the Ku-band, offering a further advantage for angular resolution. There are off-the-shelf Ku-band low-noise-block converters (LNBC) which can take an external reference, and these can be used to provide coherent translation to L-band for signals from

different elements of the array, by distributing a common local oscillator reference. Based on these considerations, we have included C and/or Ku-band RF subsystems to co-exist with a simple L-band antenna (and LNA) for our array element, as illustrated in Fig. 2.

III. INTERFEROMETRIC OBSERVATIONS OF WORLDSPACE SIGNALS

As an illustration, we present in this paper some results obtained in an experiment in satellite interferometry by observing the L-band signals from a Worldspace satellite (which had a coverage in the Indian subcontinent during the observations) using commercial Yagi antennas located at two different GMRT sites. In this experiment, we exploited the spare capacity of the GMRT fibre-optic network to obtain a long baseline L-band interferometer. The specific sites chosen for this experiment were those in the original plan of the GMRT (and hence with proper termination of fibre-optic cables) but where no GMRT antenna were installed due to a small reduction of the GMRT antennas arising from funding constraints. These two locations were used to position a pair of low-cost antennas (meant for receiving digital audio signals from Worldspace) effectively separated by about 11.2 kilometres. The L-band signals received by these low-cost antennas were brought to a central location using the GMRT fibre-optic network. They were then down-converted to 70 MHz IF, using a common local oscillator, digitized and recorded using a PCI data acquisition card.

The recorded data were then processed by a simple software to cross-correlate signals from the two antennas after suitable delay compensation. The slow relative motion of the satellite with respect to the Earth results in fringes visible in the estimated cross-correlation, as shown in Fig. 3. The figure shows two sets of fringes from a one-hour stretch of data, with a one-hour gap between the two sets. These are typical interferometric fringes, in which a linear variation of path length difference is translated into a sinusoidal variation of the cross-correlation. By counting cycles and measuring the residual phase offset, one can infer that the time taken for a path length variation of 25 cycles is about 7220 seconds, implying that the mean time for path length to vary by one wavelength (20.17cm) was $7220/25 = 288.8$ seconds. The signal-to-noise ratio was adequate for achieving an accuracy of a fraction of degree in phase estimation, with a one-second integration. Thus, one can conveniently detect a tiny relative displacement (by a fraction of a millimetre) of the satellite along a direction parallel to the line joining the two antennas.

Further experiments using the L-band navigation (WAAS) signals and the Ku-band signals from GSAT-8 are planned soon after the satellite payloads are officially commissioned for regular services after the in-orbit-tests. The results will be presented elsewhere.

Receivers for Satellite Interferometry

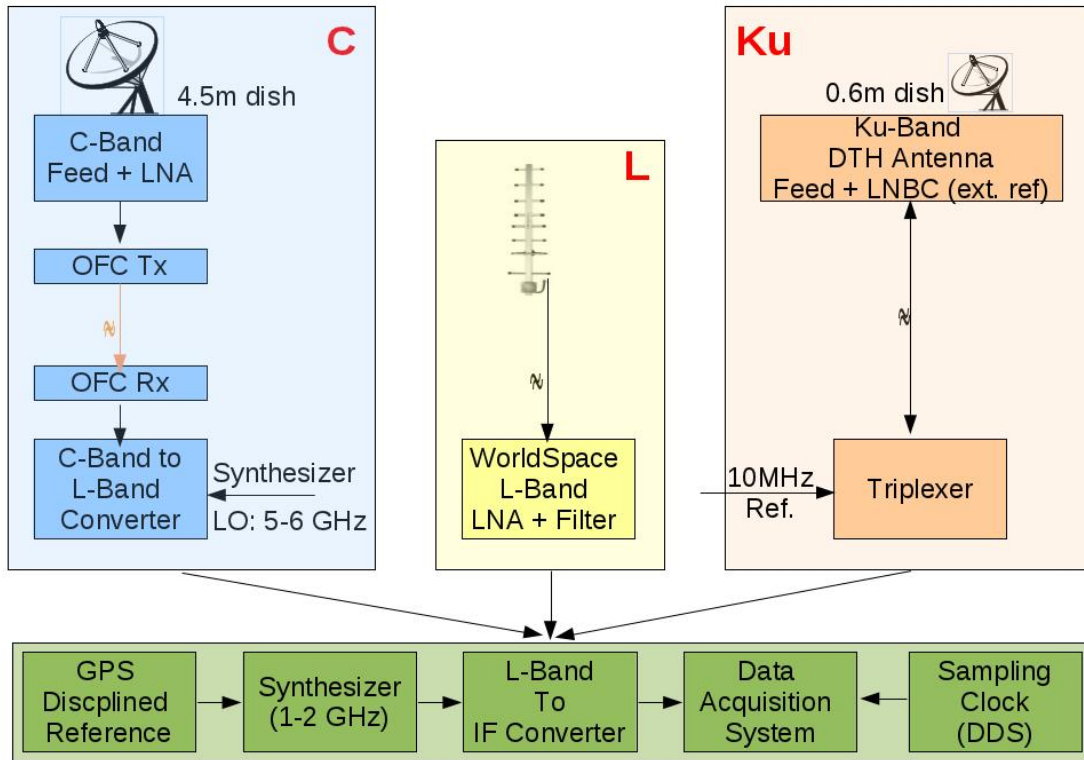


Figure 2. Receivers at each array element for satellite interferometry

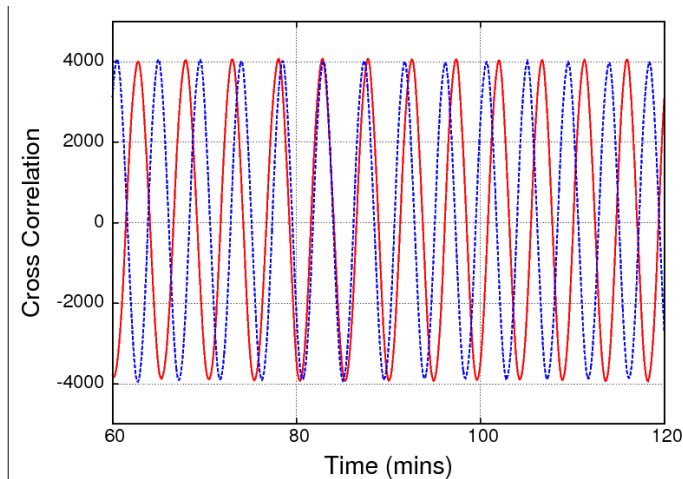


Figure 3. Plot showing the fringes in two independent 1 hour stretches, separated by an hour.

CONCLUSIONS

An important conclusion drawn from the above experiments was that the achievable accuracies for satellite interferometry provide valuable data for satellite orbit estimation even with much slower phase variations, as would result from a short

(in-campus) baseline. With this in mind, the facility being established by us is planned to be realized in a relatively short baseline, within the campus of the Raman Research Institute.

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